IN-LINE INSPECTION OF CO_2 PIPELINES – OPPORTUNITIES AND CHALLENGES

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ABSTRACT

In-line inspection (ILI) is a widely accepted basis for the integrity management of transportation pipelines. The inspection of pipelines transporting hydro-carbons is day to day business in the industry. Recently, a discussion has been started about the ability to inspect CO_2 pipelines. This discussion was triggered from ongoing efforts dealing with the implications of future carbon capture and storage (CCS) programs. The inspection of high pressure pipelines carrying liquid or supercritical CO_2 requires a dedicated set-up of the in-line inspection tools. Special materials with a proven resistivity to solvents like CO_2 have to be selected, dedicated operational procedures with regards to the launching and receiving of the ILI tools have to be followed.

The deterioration mode of pipelines due to an aggressive medium, in particular, if combined with traces of water or H2S requires a dedicated ILI program. Thus, for example the requirement to monitor corrosion growth rates can be addressed by a base line survey prior or shortly after transition to CO_2 service. In case of new build pipelines such a base-line survey can be conducted directly after commissioning of the pipeline. Also the inspection frequency may have to be increased to monitor changes and to ensure, that the operation of the pipeline is not detrimental to the integrity of the pipeline.

The inspection of CO_2 pipelines can be based on the vast experience from in-line inspection gathered over the last decades. This is a great opportunity for the integrity management and safe operation of these new or converted assets. The challenging operational conditions of high pressure, very dry, liquid gases have to be technically addressed by the inspection service.

Recent studies have shown that most of the available inspection technologies like magnetic flux leakage (MFL), eddy current (EC) and electro-magnetic acoustic transducer (EMAT) can be utilized. Currently investigations are started to assess a potential inspection with piezoelectric ultrasonic testing (UT) probes. The application is currently compromised due to the very low speed of sound in liquid CO_2.

A CHALLENGING MEDIUM

Inspection and cleaning of pipelines is common practice in the pipeline industry. Although many can easily be inspected, others remain unpiggable. A main cause which hinders inspection/pigging, is the medium going through the pipeline. Such difficult media include diluents and other aggressive chemicals, like for example ammonia. One of the most challenging media is carbon dioxide (CO_2). This might be surprising, since this chemical compound is quite present in our environment and seemingly harmless to materials. The CO_2 percentage of 0.038 % in the air occurs namely due to combustion or oxidation of carbon. Humans exhale air which contains about 4 % of CO_2. So what is the critical issue of CO_2 in pipelines?

For transportation through pipelines, CO_2 must be under high pressure and therefore is highly concentrated. It is compressed to achieve high mass flow rates and low flow velocities for optimum transport performance. This is particularly effective state of CO_2 designates the supercritical condition of the medium. In this condition CO_2 has a gas-like viscosity, but the density like that of a fluid [WATTS 2010]. Although CO_2 is not very reactive chemically, this supercritical condition makes it a very strong solvent. The size and shape of the molecules allow it to diffuse into nearly every type of rubber or plastic material, hence its critical effect on numerous parts of inspection tools, such as cables, sensors and seals.

Another critical issue of CO_2 is when it is combined with water. This mixture creates carbonic acid which causes corrosion in pipelines. Therefore, the CO_2 must be very dry when transported. This particular corrosion phenomenon has two main consequences on pigging:

- the dry surface of the pipeline causes high wear on the sliding part of the tool, especially the cups and discs
- the dry environment prevents the equalization of potential electrical conductivity.

The extreme wear on the carrying and sealing elements is a crucial issue for pigging, as the performance of these elements is the defining parameter of the achievable piggable length of the pipeline. Alternative solutions like support wheels are also affected by this extreme environment (missing or dissolved lubricants, dust contamination) yet not just because of the dry environment, but namely due to the deterioration caused by the diffusion of the CO_2 into the surface of the cups and discs.

Other effects of the dry environment in pipelines are more indirect and depend on the actual design of the inspection tool. The potential electrostatic charge can be built up by the movement of the cups along the pipe wall. This conductivity is stored on the surface of the entire tool and can create very high voltages between the tool and the pipeline. This will be discharged either by a conductive contact or jump over. Depending on the position and intensity of this discharge and the involved areas of the inspection tool, this can lead to serious damage to electronic parts. Particularly fast and high performing electronic devices, such as those in in-line inspection tools, are sensitive to these electrical discharges.

A further effect of the diffused medium in the plastic materials is caused by the decompression of the tool environment. That means the surrounding pressure is reduced by venting the receiver of the pipeline. The Joule-Thomson Effect indicates that the expansion of a gas leads to decreased temperatures. This can result in temperatures far below zero degree C with corresponding effects on the electronic and plastic materials of the tool. However, when the tool is not operating or moving anymore, the consequences of this are not critical. Explosive decompression also affects the integrity of an inspection tool, when the medium diffuses into plastic materials. Since no plastic and rubber materials are completely impermeable to gas diffusion, a certain volume of the CO_2 will be absorbed into the material. When the pressure in the receiver is released, CO_2 will partly diffuse out of the material. In some areas of the material however, there will be an accumulation of trapped CO_2. With reduced external pressure the CO_2 will expand in the material creating bubbles on the surface. These bubbles may collapse again or burst if the amount of CO_2 it too large. This is called “explosive decompression” and is a very detrimental phenomenon for cables, elastomeric or rubber parts on an inspection tool.

SOLUTIONS TO OVERCOME CO_2 CHALLENGES

The previous description of the particular challenges defines the scope of required preventive actions or design measures, which will be described in the following sections

Wear on pigging tools

CO_2 pipelines can be as long as other transport pipelines since they connect electrical power plants with old reservoirs. Therefore, the wear resistance is a minimum requirement for a cleaning or inspection tool because of this critical issue. As described in the previous section, CO_2 creates a critical environment inducing wear of elastomeric cups on inspection tools because of its extreme properties as a solvent. Both conditions also affect other pipeline systems in numerous other media. ROSEN has therefore developed techniques and strategies to mitigate these detrimental effects on cups and discs.

Cups and discs have two basic functions on a pigging tool: carrying and sealing. Both of these are factors determine the success of an inspection run. They can be provided by separated elements (guiding and sealing discs) or can be combined in a cup. If a carrying element is subjected to too heavy wear, the sealing could break causing a risk of a high bypass rate and possibly induce a stop of the tool movement. Sealing elements can therefore cope with excessive wear, as long as the carrying function is working. For this reason, it is most important for a pigging tool be able to support all segments properly, especially the pulling unit.

There are several options (besides the cup and disc material itself) to carry or support a cleaning or inspection tool. These are support wheels, wear re-enforced cups or brushes. The magnetizer unit of a Magnetic Flux Leakage (MFL) tool is an effective support for the entire tool. These basic solutions can define an adaptation to a tool setup. Each solution though, has its pro and cons and cannot be used for every application. For example, support wheels for small tool sizes are elaborate and not very reliable, particular in extreme media. In addition, the actual measures have to be defined considering the relevant pipeline and the planned tool as well as the operating conditions and further experience.

The effect of the solvent properties of CO2 cannot be compensated 100% in an elastomeric material, particularly in those which are exposed to supercritical carbon dioxide. However it is possible to mitigate the negative effects of the phenomenon by adapting the composition of the plastic.

An extreme example for the potential of an adapted polyurethane (PUR) composition is shown in figure 1. It shows a test sample including a standard PUR disc after 48 hours of exposition to high pressure ammonia. The remaining PUR is only a mass of steaming material. After the ammonia has been diffused, the material falls into a heap of ashes clearly showing that standard PUR is absolutely not usable in ammonia. ROSEN has therefore developed an ammonia resistant PUR which is shown in figure 2. The shown 6" pull unit is fully equipped with ammonia resistant PUR and two ring brushes for support, and is able to pull a 6" MFL tool through an 82 km long pipeline, in total an exposition time of 60 hours.

Although this is not comparable to the less dramatic effect of CO_2 it shows the basic potential of PUR development. The actual experience with ROSEN PUR in CO_2 pipelines is very good. It shows remarkably increased wear resistance, and practically no extreme swelling of the material.

Sensors, cables and seals

In-line inspection (ILI) tools are typically equipped with various sensor cables and corresponding cable connectors. In many cases, these sensors are partly built of various plastic materials (e.g. rubber). Elastomeric materials are particularly affected by a CO_2 environment. These effects are generally the diffusion into the material which after depressurization can cause surface swelling invariably lead to explosive decompression. As CO_2 is not chemically aggressive, pure diffusion does not cause problems. The performance of ILI tools therefore, is not affected until it operates under pipeline pressure. Only after a run, when the pressure is released from the receiver, the effect of the CO_2 decompression become visible. This does not necessarily occur directly after the decompression, but namely some time later. Only when swelling of the material inducing explosive decompression occurs there high potential to damage connections, wires or other electronic components mechanically, due to massive deformation. The dimension of the affected area depends on the type of plastic material, the exposure time and temperature of the surface, as well as the thickness. In thin layers, the risk of swelling, bubbling or explosive decompression is extremely high.

Typically, the decompression is carefully conducted to avoid the mentioned effects. Fortunately, this operational aspect is not affecting the data quality, since the effect occurs in the receiver only and not during inspection. The replacement of damaged parts of an ILI tool is very costly, if required after each inspection run. Therefore, it will be a future goal to find more durable materials.

Electrical discharge

As the discharge of electrical charge is a common occurrence in in-line inspection, ROSEN has already developed a series of measures to cope with it. For example, ROSEN has developed conductive PUR for the cleaning and ILI tools to prevent the built up of extreme electrostatic charge. Additionally, the conductive material allows a low discharging current, avoiding the high current discharge at metallic contacts. Furthermore, protective measures are made inside the electronics to mitigate the effect of discharge if this cannot be prevented completely.

CASE STUDIES

In the following section, some examples for inspections in high pressure CO_2, as well as another relevant extreme pipeline, are presented. The main focus is directed on the abrasion of the tool components and of course, on the overall success of the inspection. The example considers effects in an ethylene pipeline. Although ethylene is not directly comparable to CO_2, it is similar in the effect on inspection tools, particularly regarding the wear but also with the swelling of plastics.

24” pipeline, 131 bar CO_2, 116 km

The pipeline transported CO_2 at a high pressure of 131 bar and a launching temperature of about 16 °C for 116 km. Because of a very low flow rate, the inspection duration was about 180 hours. The line was inspected with two separate tools and technologies: an electronic geometry tool (RoGeo) and a MFL tool. Figure 3 shows a rear view of the RoGeo tool after the run. The run was successful and no damage was reported. This is confirmed by the picture, where there is no visible effect or extreme wear after a long run and a long exposition time. The snow like substance visible on the tool is carbon dioxide snow which forms directly as the CO_2 steams out into the air. This occurs due to decompression. Several hours later in the workshop, the plastic and rubber parts of the tool begin to show signs of bubbling (figure 4).

Clearly, the cups and discs are not remarkably affected. The cups do not show deformation compared with the buffer, and do not even have bubbles. This is a first indication of the performance of the different materials. The cups and discs of RoGeo are produced with a hardness of 85 Shore whilst the buffer is manufactured with a different and softer material (65 Shore) and the RoGeo sensor is casted with a similar composition to that of PUR.

The inspection with the MFL tool was successful and the tool showed no extreme wear on the cups and the disc (see figure 5) such as those on RoGeo. A difference is appearance of the high number of cables a short time after receiving. As shown in figure 6 the cable loop is completely swollen already shortly after the run. One day later, the cables are visibly back to their original condition. On this tool a little effect on the guiding disc could be observed (figure 7). Back in the workshop after the run, some bubbles and deformations are visible, but not to a disconcerting extent.

24” pipeline, 134 bar, 120 km

This pipeline was also inspected with a geometry and a MFL tool. Both runs were also successful and showed no unusual wear even after an exposition time of about 77 hours. But again the PUR reacted as already described. The cups and guiding discs show little or no damage after depressurization, but the RoGeo sensor and all the cables above it had some swelling and bubbling on the surface. The entire surface of the PUR body of the sensor is covered with large and small bubbles, as well as deformations.

The result for the MFL run was similar: the guiding discs and cups were in good condition, however the cables, sensors and connections were affected (same result as displayed in figure 6).

8” pipeline, 60 bar, ethylene, 108 km

This example was chosen because of its extreme conditions and small size. The line is known to be critical. The client could not get a cleaning tool into the receiver because of the medium (very dry), the amount of debris in the pipeline (typical for ethylene), and the pipeline length in relation to the small size. Therefore, an adapted cleaning tool was designed to cater for these criteria. After successful performance of the cleaning tool, it was used also as a pull unit (figure 8) for the MFL inspection tool. Because of the expected very heavy abrasion, further modifications were made to prevent excessive wear of the cups of the electronic units. These were reinforced with sliding bolts inside the cups’ surfaces to reduce the wear on the lips of the cups. Although heavy abrasion is clearly visible, the modification provided enough resistance to allow a successful line inspection.

INSPECTION TECHNOLOGIES FOR DENSE CO_2 PIPELINES

One of the major concerns for the integrity of CO_2 pipelines is an aggressive progressing internal corrosion caused by potential impurities like H2S or H2O in the dense phase of CO_2. High corrosion rates and deterioration of the internal pipeline surface is the consequence.

Another aspect is the assessment of pipelines, which are currently operated with another hydrocarbon product, liquid or gas and which are planned to be changed in service towards CO_2 operation. Typically existing gas pipeline systems cannot easily been modified to transport dense phase CO_2 since the existing compressor units have to be exchanged. Therefore, these systems can only be modified to CO_2 operation in the gas-phase. However, in these cases as well, the same applies as mentioned above, in that H2S or H2O impurities may lead to serious interior pipeline corrosion.

In either case, it is recommended to perform a baseline survey to allow monitoring of potential corrosion growth and determination of the corrosion growth rate. To achieve accurate results, it is required to use the same inspection technology for the subsequent inspections.

Although the dense CO_2 phase reacts like a liquid with regards to some of its physical properties, the application of liquid coupled UT is not possible with the required accuracy. The reason for this is the low acoustic impedance of the CO_2, which is due to the low velocity of sound and the strong dependency of velocity and density from temperature and pressure. A detailed analysis of the basic relationship has been presented by [COLINA ET AL. 2003].

Therefore, the inspection method of choice is the well established MFL technology. This technology is independent from the medium, its pressure and temperature. Nowadays, it is possible to combine the MFL inspection device with a high-resolution geometry unit to gain more information from a single inspection survey. Figure 9 shows a 24” ILI tool, where the front unit is equipped with the MFL technology, while the rear unit is dedicated to high-resolution geometry assessment. ROSEN has developed a technology for the detection and assessment of shallow internal corrosion (SIC) which can be added to the geometry unit. This eddy current based add-on is an additional independent methodology supporting the MFL findings and reducing the detection threshold for internal metal loss features to 0.8 mm depth. The eddy current sensor (figure10) delivers an accurate map of the internal pipeline surface (figure11). The combined technology delivers accurate results for the assessment of corrosion. The efficiency precision of the combined evaluation has been described by [HUYSE ET AL. 2010].

To derive reliable corrosion growth rates, a two tear process is suggested. At first, the reported anomalies from subsequent inspections are mapped against each other. Secondly ,the normalized inspection signals are compared to compensate the systematic and random error from both runs. An example of such a comparison is given in figure 12. Data from three subsequent inspection surveys are shown. The signal pattern of a girth-weld can clearly be identified and is used for reference. The individual inspection report only gives the maximum depth of the corrosion area in question. However, comparing the raw ILI data clearly shows, that light corrosion is already present. This corrosion has not been reported, since it was below the contractually agreed reporting threshold. Nevertheless, for the calculation of a corrosion growth rate and to better understand the mechanism of deterioration, the additional information drawn from the raw data is crucial.

SUMMARY

The current development of the carbon capture and storage (CCS) technologies is preceeding the inspection of pipelines transporting CO_2. Because of its particular properties, the inspection of these pipelines are leading to additional challenges for inspection companies.

The critical properties of CO_2 transporting pipelines are the very dry conditions and the CO_2’s highly volatility as a solvent. The first is mainly abrasive to the driving and carrying elements (PUR cups and disc) of an inspection tool, whilst the second has an impact on the plastic parts, mainly after decompression at the end of a run. Consequently this can lead to damages on all parts such as sensors, cables, seals and connections. The effect of the CO_2 is enhanced when it is operated under supercritical conditions as some of the properties are gas-like even under very high pressure.

Due to the experience with CO_2 and other critical media and pipeline conditions, several solutions are presented to overcome the challenges. For example the wear on the ROSEN standard PUR was found not to be different to comparable pipelines transporting other media. Nevertheless, the different compositions of PUR clearly showed varying behavior after the run. The hard PUR composition for the guiding discs and cups were nearly unaffected compared to other softer materials. Additionally, they showed they could cope with highly abrasive media in small diameter pipelines .

It also was shown, that the solvent effect of CO_2 has a more critical impact on the inspection tools. As the real effect occurs only during and after decompression, the inspection itself is not affected. But the swelling and bubbling of the different plastic materials can damage cables and sensors. Therefore, these parts have to be replaced after use with the according consequences for inspection costs and efforts. But with increasing demand for these tools adapted design and material development are likely.

The performance of the inspection technology is not affected by medium in this case. However, the special nature of CO_2 require a more thorough inspection and assessment program than other (hydrocarbon) pipelines.

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FIGURES

Figure 1: Polyurethane cup samples exposed to Ammonia over a period of 24h.
a) Optimized composition b) Standard polyurethane

Figure 2: Ammonia PUR on a 6” pull unit after 82 km and 60 hours exposition time.

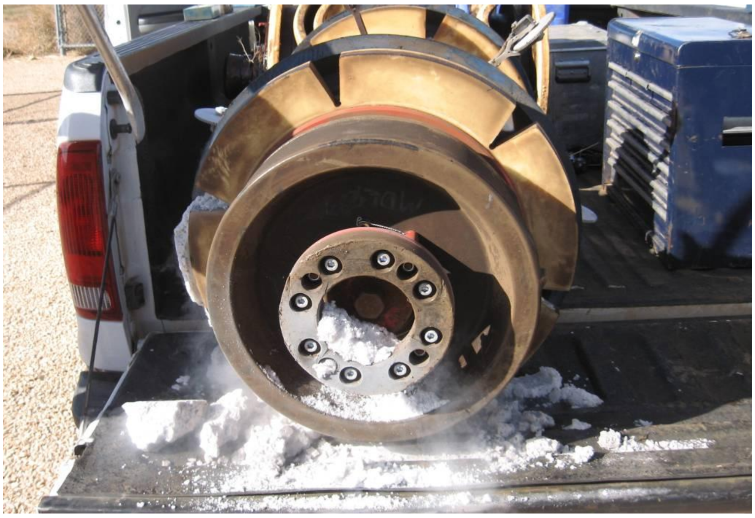

Figure 3: Geometry tool after 116 km in high pressure CO_2.

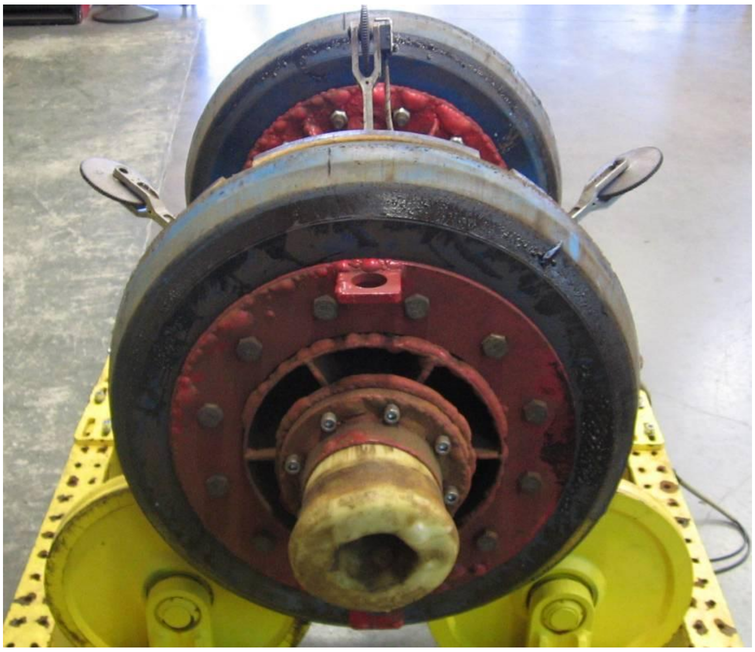

Figure 4**:** Front view on ROSEN's Electronic Geometry tool, hours after the run with swollen buffer and bubbling painting.

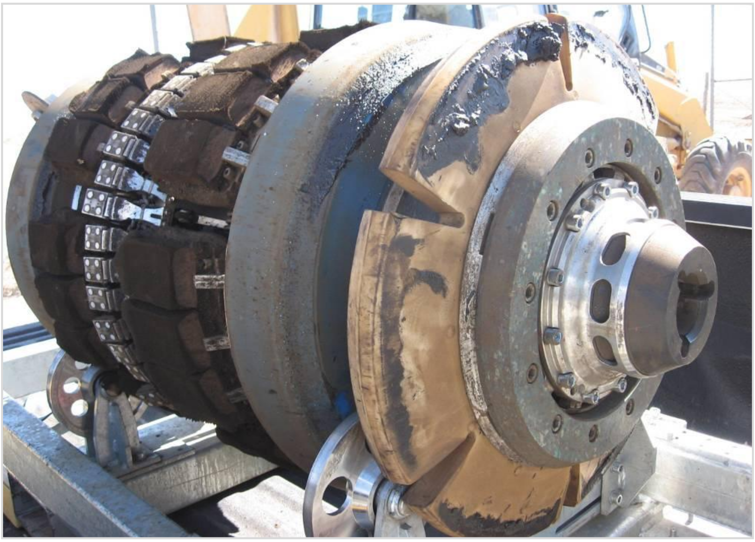

Figure 5**:** MFL tool after the run in 116 km high pressure CO_2.

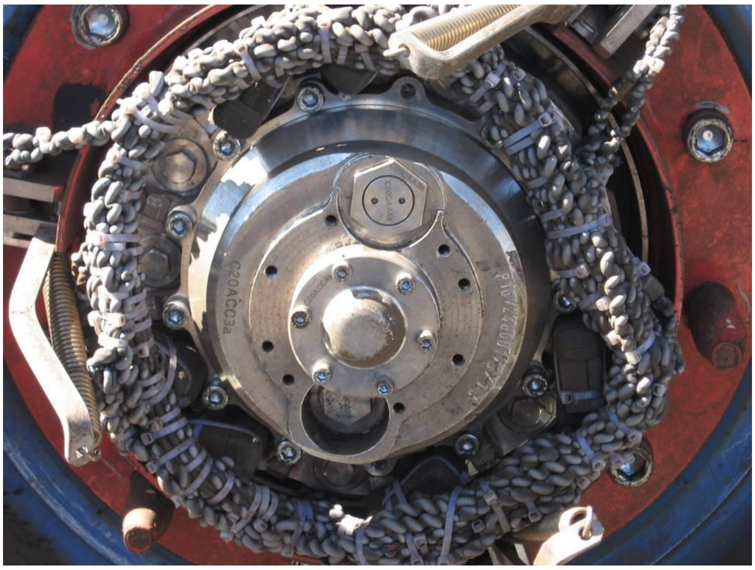
Figure 6**:** Rear view of 24” MFL tool after the run with extremely swollen cables.

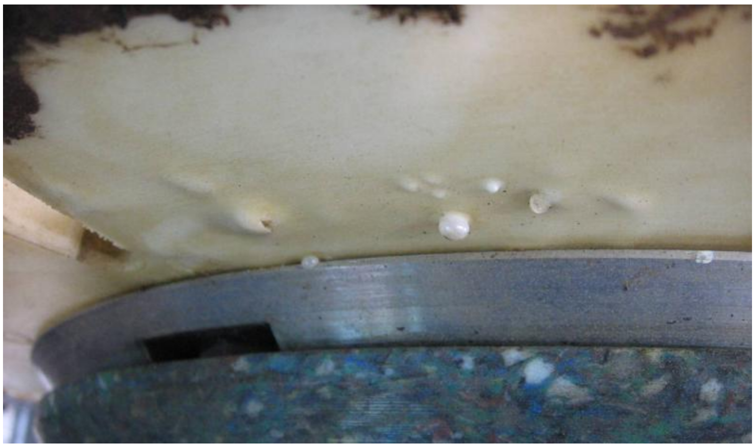
Figure 7: Guiding disc of 24” MFL in the workshop with visible bubbles.


Figure 8: Pull unit for 8” line after 102 km in 60 bar ethylene.

Figure 9: Combined in-line inspection with MFL technology (front), high-resolution geometry assessment (rear), and eddy current sensors for the detection and characterization of shallow internal corrosion (rear).

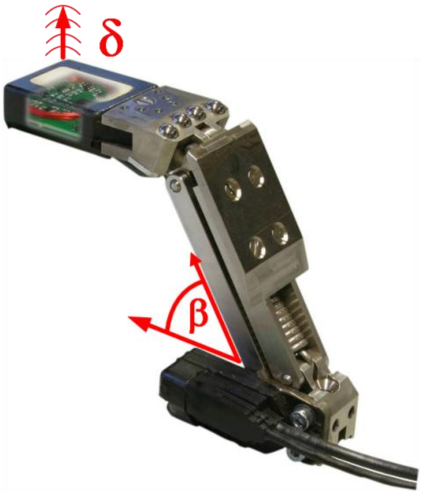

Figure 10: High-resolution geometry sensor consisting of a caliber sensor (β) and an eddy current sensor (δ) measuring the lift-off and internal corrosion.

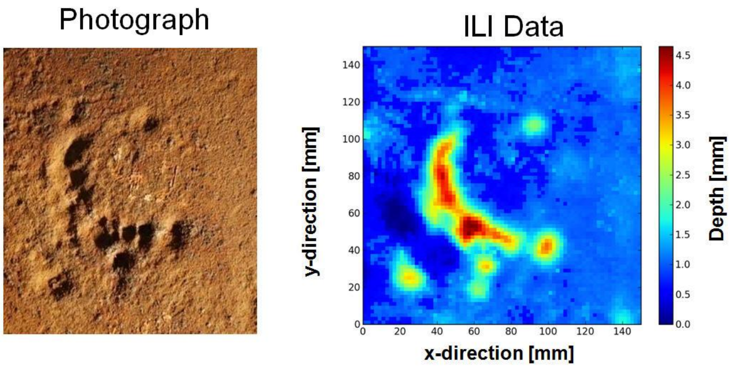

Figure 11: Comparison of the high-resolution mapping data for shallow internal corrosion, and the corresponding photograph.

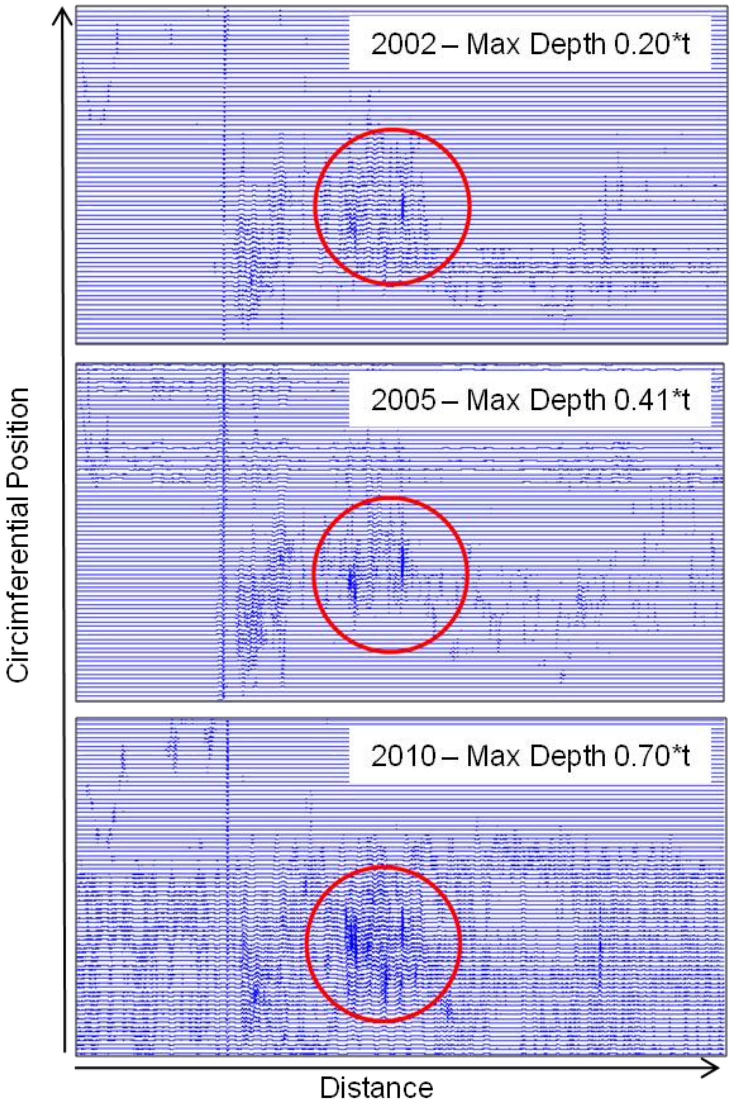

Figure 12: Example of corrosion growth monitoring based on an MFL signal data. The individual inspection report depicts the maximum depth for general corrosion only. However a comparison of the normalized raw data indicates sub-threshold corrosion growth in the surrounding area of the reported anomaly.